

Lecture 15: The Details of Joins

(and bonus!)

What you will learn about in this section

1. How to choose between BNLJ, SMJ
2. HJ versus SMJ
3. Buffer Manager Detail (PS#3!)
4. ACTIVITY: Buffer Manager DETAIL!

Nested Loop Joins

Notes

- We are again considering “IO aware” algorithms:
care about disk IO
- Given a relation R , let:
 - $T(R)$ = # of tuples in R
 - $P(R)$ = # of pages in R
- Note also that we omit ceilings in calculations...
good exercise to put back in!

Block Nested Loop Join (BNLJ)

Given $B+1$ pages of memory

Cost:

$P(R)$

Compute $R \bowtie S$ on A :

for each $B-1$ pages pr of R :

for page ps of S :

for each tuple r in pr :

for each tuple s in ps :

if $r[A] == s[A]$:

yield (r,s)

1. Load in $B-1$ pages of R at a time (leaving 1 page each free for S & output)

Block Nested Loop Join (BNLJ)

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for each $B-1$ pages pr of R :

for page ps of S :

for each tuple r in pr :

for each tuple s in ps :

if $r[A] == s[A]$:

yield (r, s)

Cost:

$$P(R) + \lceil P(R)/B \rceil P(S)$$

1. Load in $B-1$ pages of R at a time (leaving 1 page each free for S & output)
2. For each $(B-1)$ -page segment of R , load each page of S

This line is called $P(R)/B-1$ times; the loop iterates over the entire relation S $P(R)/B-1$ times (ceiling!)

Block Nested Loop Join (BNLJ)

Given $B+1$ pages of memory

Compute $R \bowtie S$ on A :

```

for each B-1 pages pr of R:
  for page ps of S:
    for each tuple r in pr:
      for each tuple s in ps:
        if r[A] == s[A]:
          yield (r,s)
  
```

Cost:

$$P(R) + P(R)/(B-1) P(S)$$

1. Load in B-1 pages of R at a time (leaving 1 page each free for S & output)
2. For each (B-1)-page segment of R, load each page of S
3. Check against the join conditions

BNLJ can also handle non-equality constraints

Block Nested Loop Join (BNLJ)

Given $B+1$ pages of memory

Compute $R \bowtie S$ on A :

```

for each B-1 pages pr of R:
    for page ps of S:
        for each tuple r in pr:
            for each tuple s in ps:
                if r[A] == s[A]:
                    yield (r,s)
  
```

Cost:

$$P(R) + P(R)/B - 1 P(S) + \text{OUT}$$

1. Load in B-1 pages of R at a time (leaving 1 page each free for S & output)
2. For each (B-1)-page segment of R, load each page of S
3. Check against the join conditions

4. Write out

BNLJ: Some quick facts.

- We use $B+1$ buffer pages as:

- 1 page for S
- 1 page for output
- $B-1$ Pages for R

$$P(R) + P(R)/(B-1) P(S) + \text{OUT}$$

- If $P(R) \leq B-1$ then we do one pass over S, and we run in time $P(R) + P(S) + \text{OUT}$.
 - Note: This is **optimal** for our cost model!
 - Thus, if $\min \{P(R), P(S)\} \leq B-1$ we should **always** use BNLJ
 - We use this at the end of **hash join**. *We define end condition, one of the buckets is smaller than $B-1$!*

1. Sort-Merge Join (SMJ)



Sort Merge Join (SMJ): Basic Procedure

To compute $R \bowtie S$ on A :

Note that we are only considering equality join conditions here

1. Sort R, S on A using **external merge sort**
2. **Scan** sorted files and “merge”
3. *[May need to “backup”- if there are many duplicate join keys]*

Note that if R, S are already sorted on A ,
SMJ will be awesome!

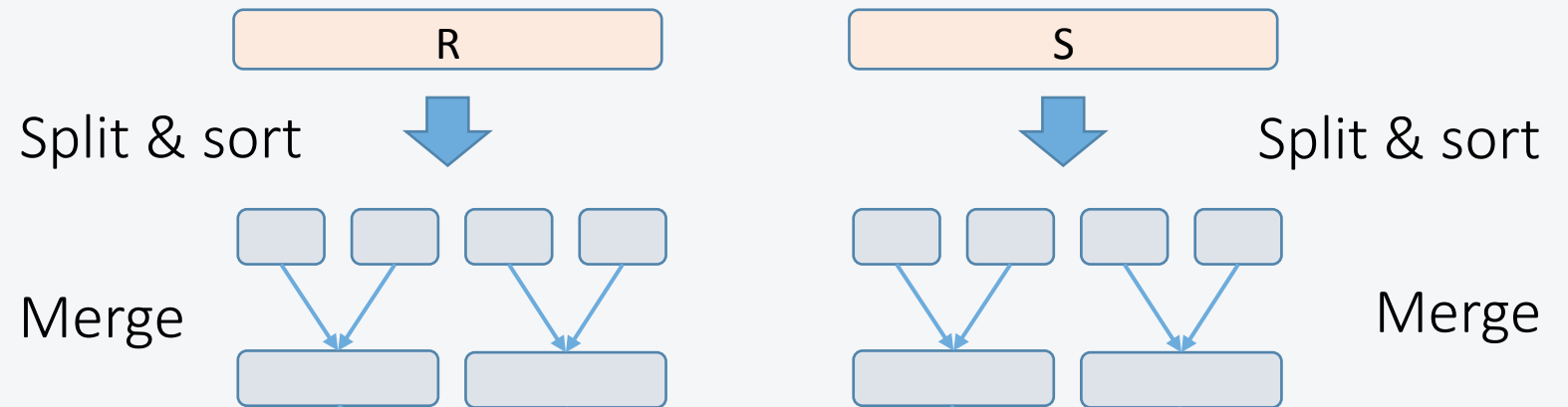
Simple SMJ Optimization

Given $B+1$ buffer pages

Unsorted input relations

Sort Phase
(Ext. Merge Sort)

$\leq B$ total runs



Merge / Join Phase

B-Way Merge / Join

Joined output
file created!

Simple SMJ Optimization

Given $B+1$ buffer pages

- On this last pass, we only do $P(R) + P(S) + \text{OUT}$ IOs to complete the join!
- If we can initially split R and S into **B total runs each of length approx** then we only need **$3(P(R) + P(S)) + \text{OUT}$** for SMJ!
 - 2 R/W per page to sort runs in memory, 1 R per page to B-way merge / join!
- How much memory for this to happen?
 - $P(R) + P(S) / B \leq 2(B+1) \Rightarrow \sim P(R) + P(S) \leq 2B^2$
 - Thus, **$\max\{P(R), P(S)\} \leq B^2$** is an approximate sufficient condition

If the larger of R, S has $\leq B^2$ pages, then SMJ costs $3(P(R) + P(S)) + \text{OUT}$!



Bonus questions.



- Q1: Fast dog.
 - If $\max \{P(R), P(S)\} < B^2$ then SMJ takes $3(P(R) + P(S)) + OUT$
 - What is the similar condition to obtain $5(P(R) + P(S)) + OUT$?
 - What is the condition for $(2k+1)(P(R) + P(S)) + OUT$
- Q2: BNLJ V. SMJ
 - Under what conditions will BNLJ outperform SMJ?
 - Size of R, S and # of buffer pages
- Discuss! And We'll put up a google form.

2. Hash Join (HJ)



Hash Join: High-level procedure

To compute $R \bowtie S$ on A :

1. Partition Phase: Using one (shared) hash function h_B per pass partition R and S into B buckets.

- Each phase creates B more buckets that are a factor of B smaller.
- Repeatedly partition with a new hash function
- Stop when all buckets for one relation are smaller than $B-1$ (Why?)

Each pass takes $2(P(R) + P(S))$

2. Matching Phase: Take pairs of buckets whose tuples have the same values for h , and join these

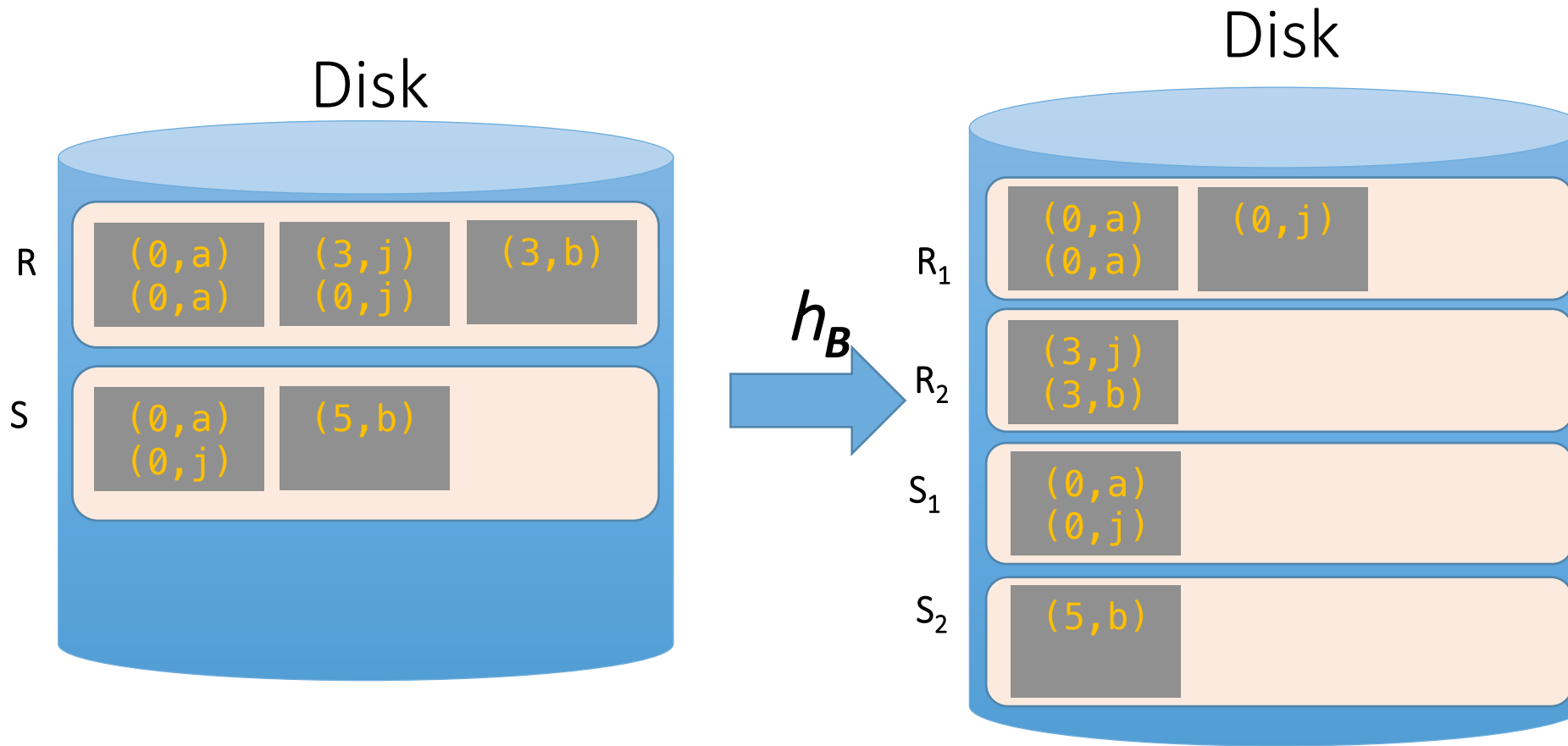
- Use BNLJ here for each matching pair.

$P(R) + P(S) + \text{OUT}$

We *decompose* the problem using h_B , then complete the join

Hash Join: High-level procedure

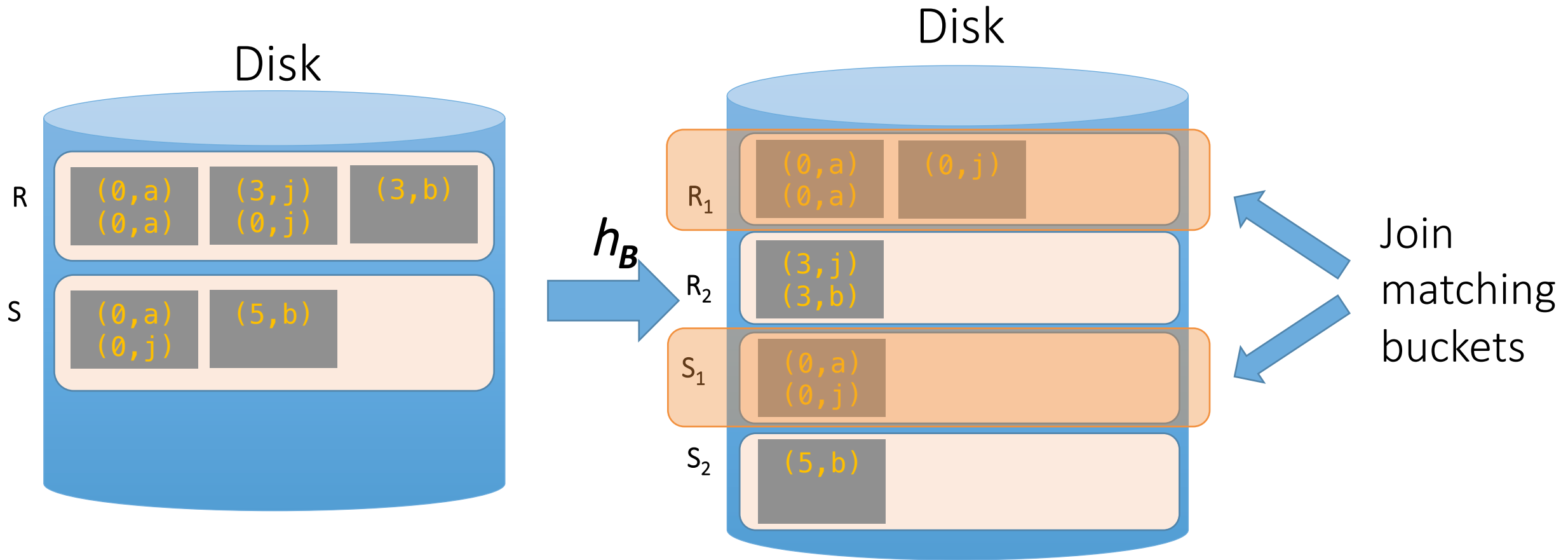
1. Partition Phase: Using one (shared) hash function h_B , partition R and S into B buckets



Note our new convention: pages each have two tuples (one per row)

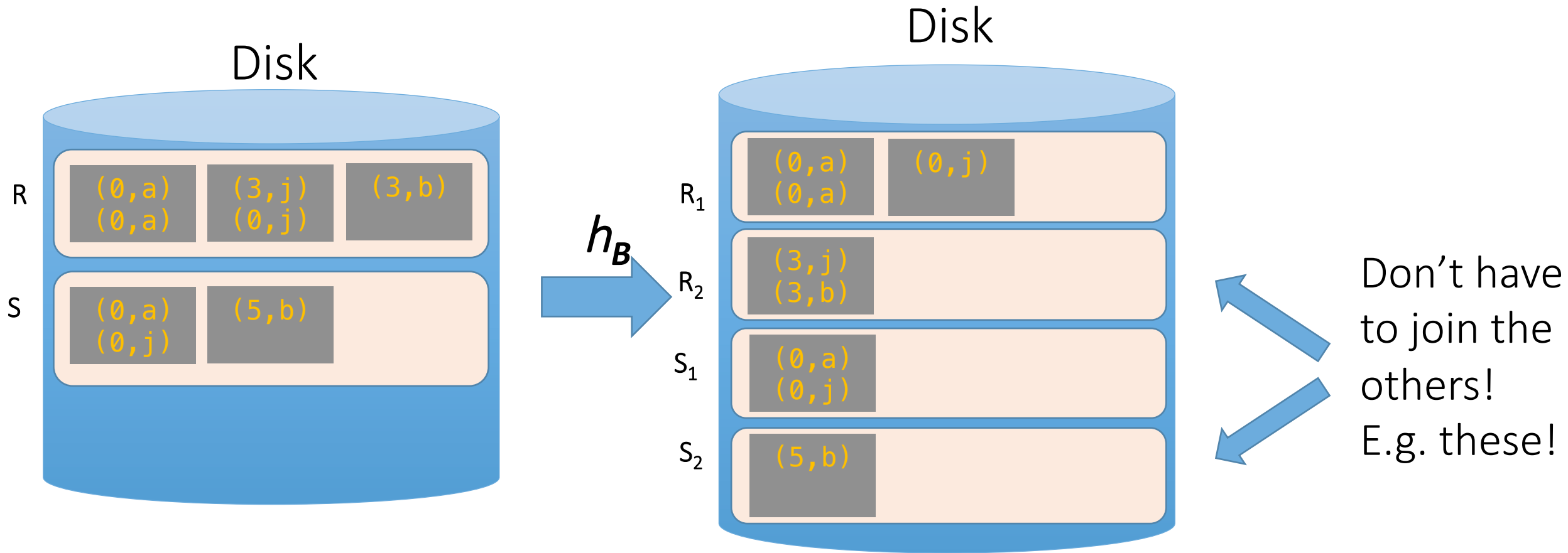
Hash Join: High-level procedure

2. Matching Phase: Take pairs of buckets whose tuples have the same values for h_B , and join these



Hash Join: High-level procedure

2. Matching Phase: Take pairs of buckets whose tuples have the same values for h_B , and join these





Bonus questions #2



- Q1: Fast little dog.
 - If $\min \{P(R), P(S)\} < B^2$ then HJ takes $3(P(R) + P(S)) + OUT$
 - What is the similar condition to obtain $5(P(R) + P(S)) + OUT$?
 - What is the condition for $(2k+1)(P(R) + P(S)) + OUT$
- Q2: SMJ V. HJ
 - Under what conditions will HJ outperform SMJ?
 - Under what conditions will SMJ outperform SMJ?
 - Size of R, S and # of buffer pages
- Discuss! And We'll put up a google form.

Sort-Merge v. Hash Join



- **Given enough memory**, both SMJ and HJ have performance:

$$\sim 3(P(R) + P(S)) + OUT$$

- “Enough” memory =

- SMJ: $B^2 > \max\{P(R), P(S)\}$
- HJ: $B^2 > \min\{P(R), P(S)\}$

Hash Join superior if relation sizes *differ greatly*. Why?



Further Comparisons of Hash and Sort Joins

- Hash Joins are highly parallelizable.
- Sort-Merge less sensitive to data skew and result is sorted



Summary

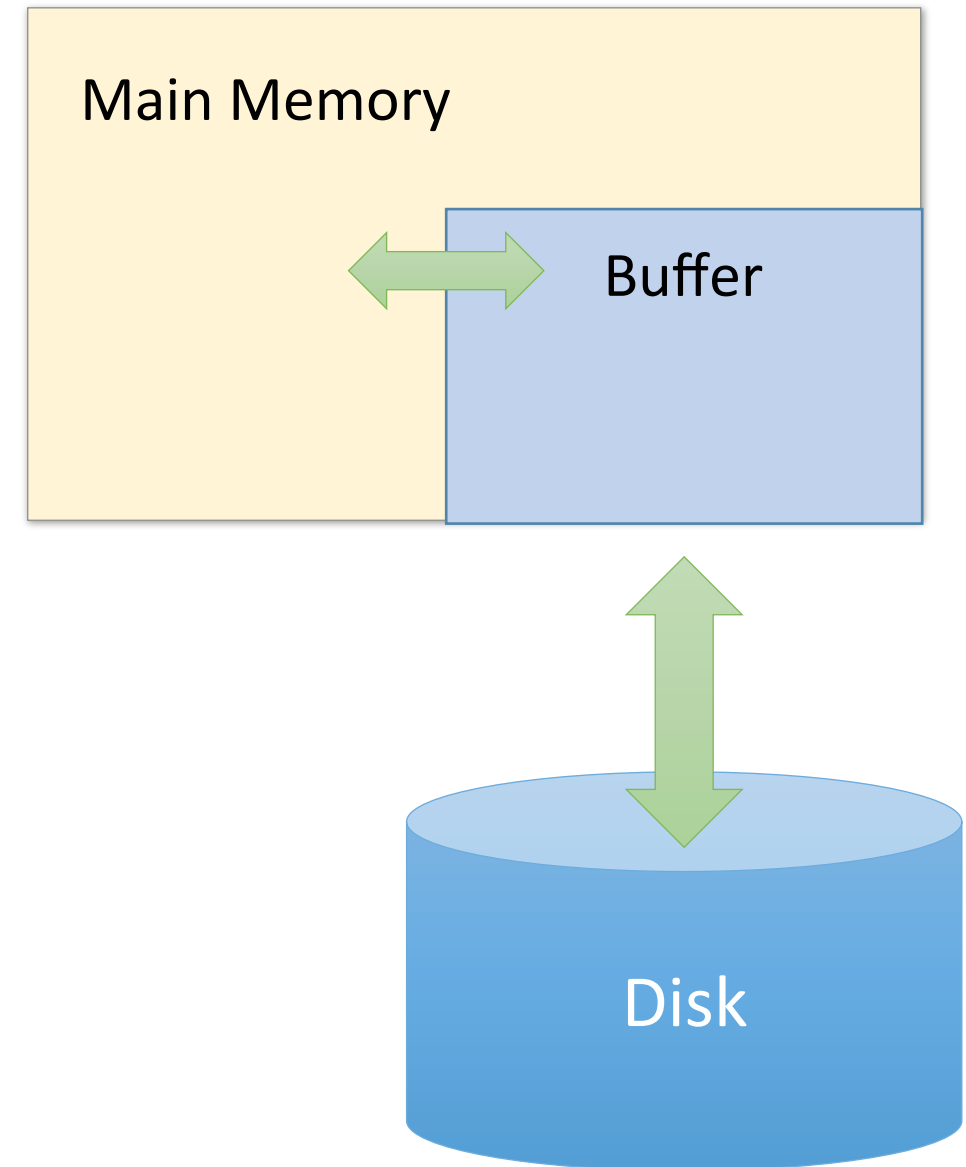
- I will ask you to compute costs on the final and PS
 - Walk through the algorithms, you'll be able to compute the costs!
- Memory sizes key in hash versus sort join
 - Hash Join = Little dog (depends on smaller relation)
- Skew is a major factor (more on PS)
- Message: The database can compute IO costs, and these are different than a traditional system.

3. Buffer Manager



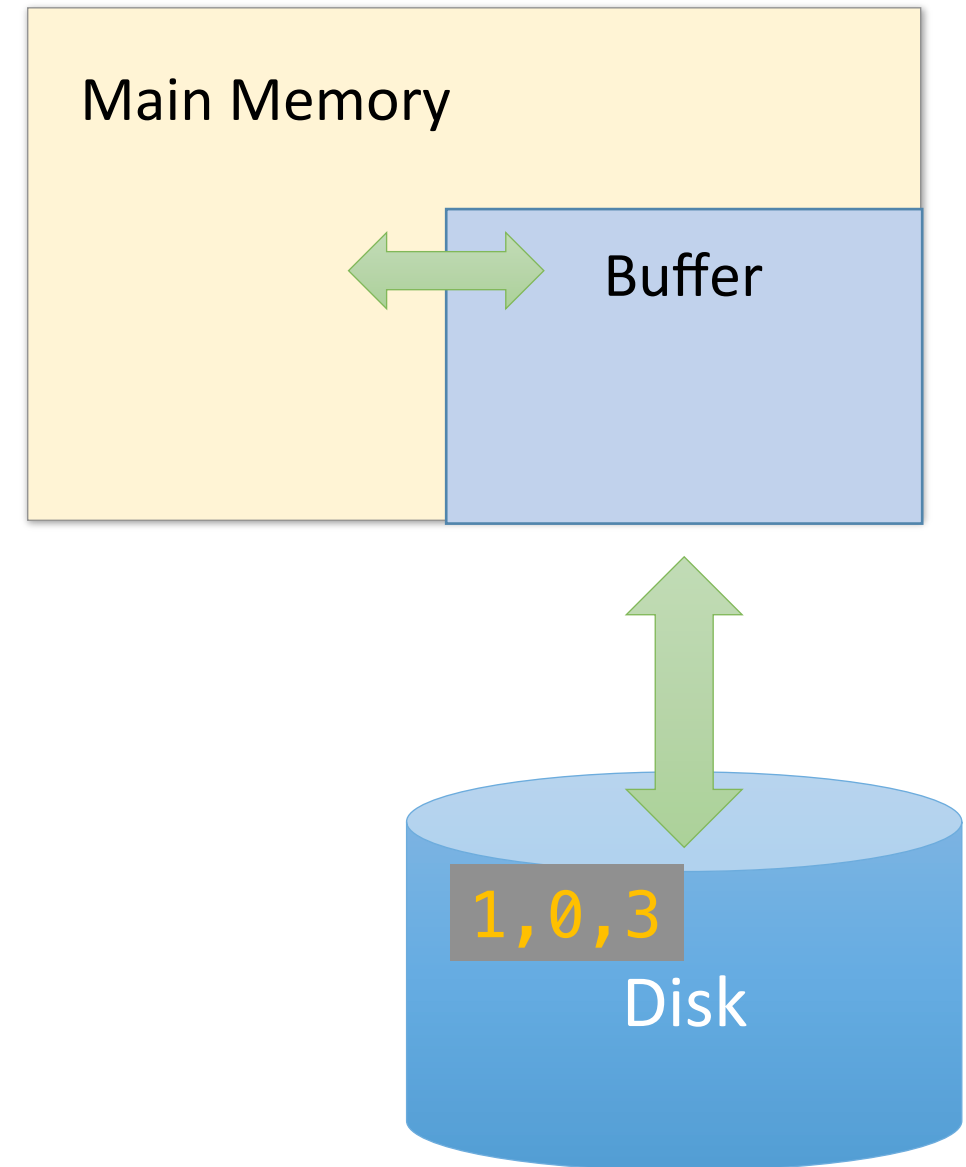
The Buffer

- A **buffer** is a region of physical memory used to store *temporary data*
 - *In this lecture:* a region in main memory used to store **intermediate data between disk and processes**
- *Key idea:* Reading / writing to disk is slow - need to cache data!



The (Simplified) Buffer

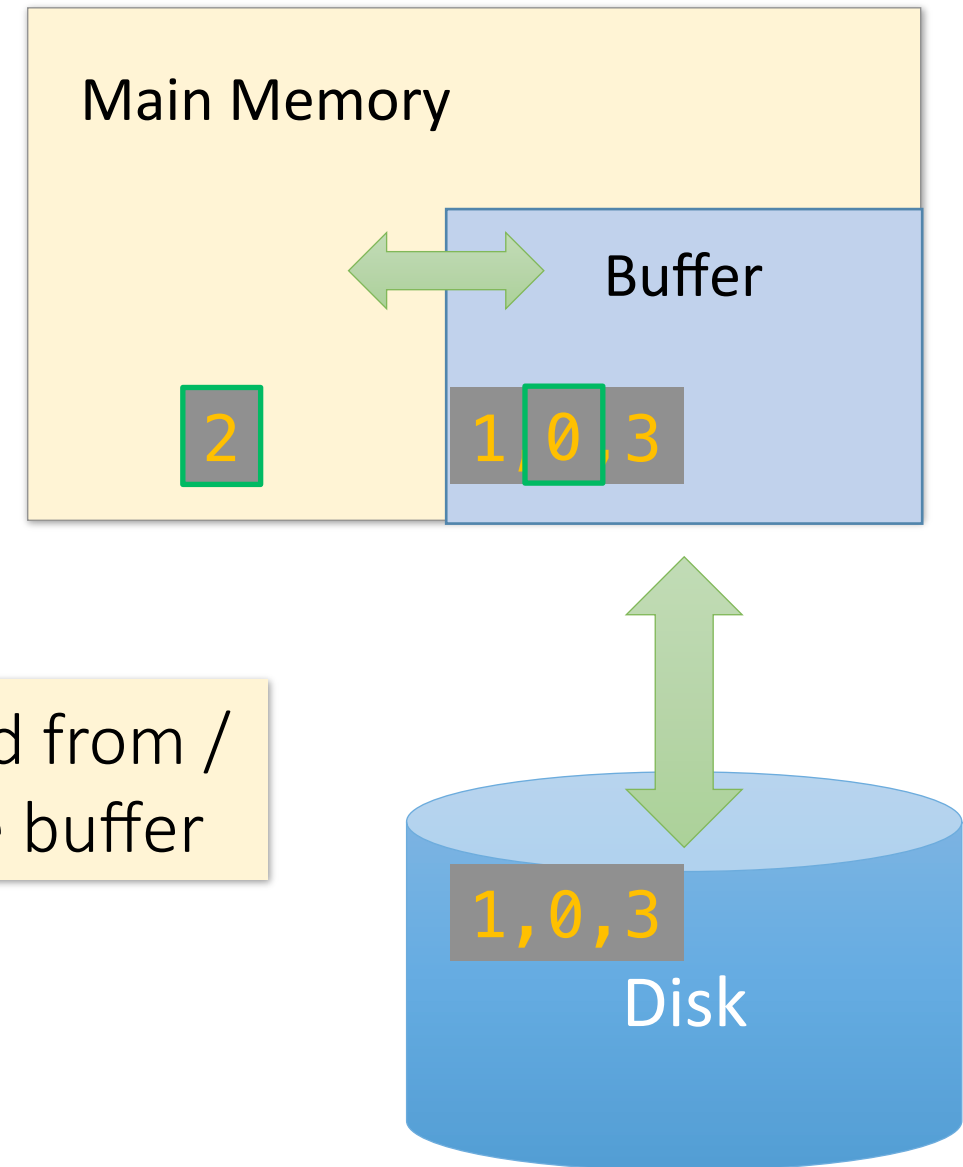
- In this class: We'll consider a buffer located in **main memory** that operates over **pages** and **files**:
- **Read(page)**: Read page from disk -> buffer *if not already in buffer*



The (Simplified) Buffer

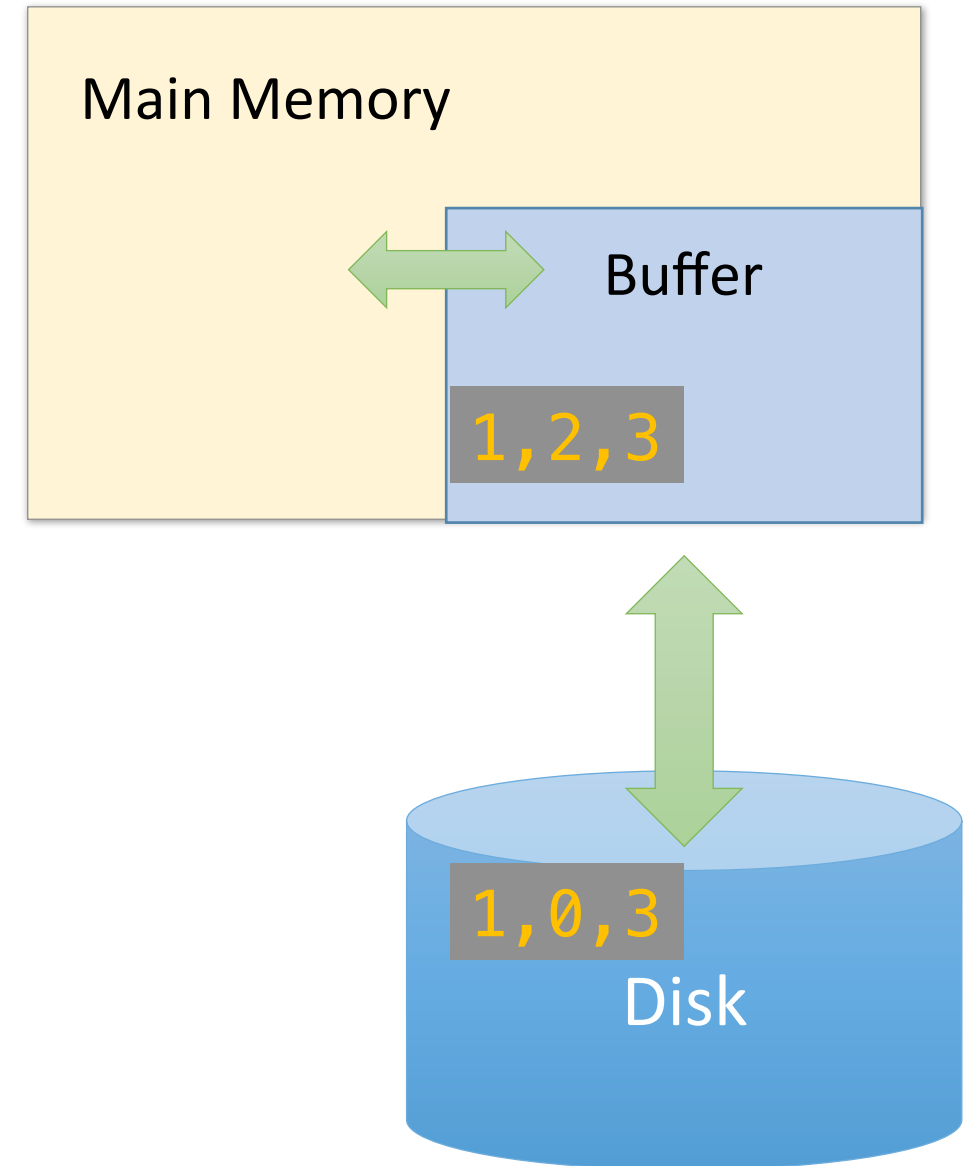
- In this class: We'll consider a buffer located in **main memory** that operates over **pages** and **files**:
- **Read(page)**: Read page from disk -> buffer *if not already in buffer*

Processes can then read from / write to the page in the buffer



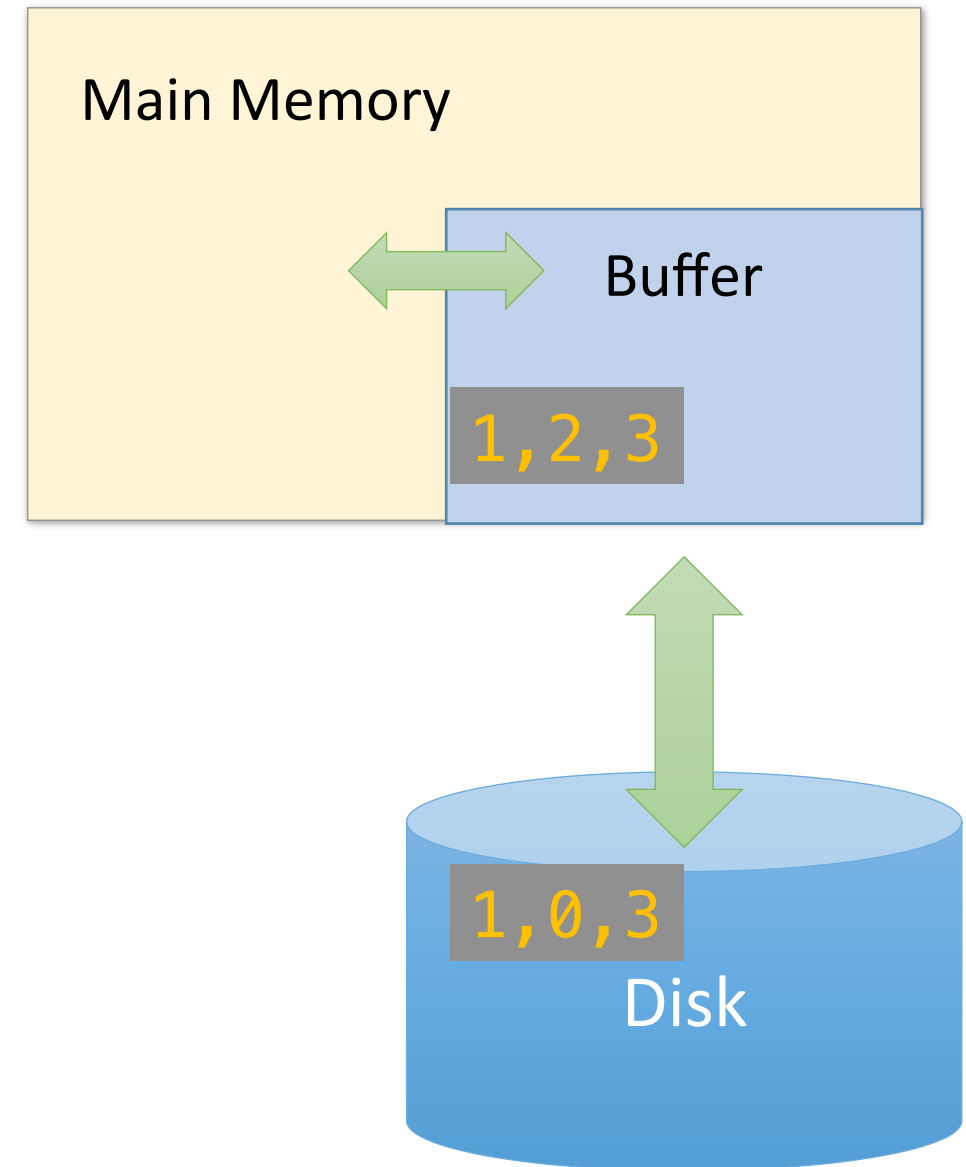
The (Simplified) Buffer

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 - **Read(page)**: Read page from disk -> buffer *if not already in buffer*
 - **Flush(page)**: Evict page from buffer & write to disk



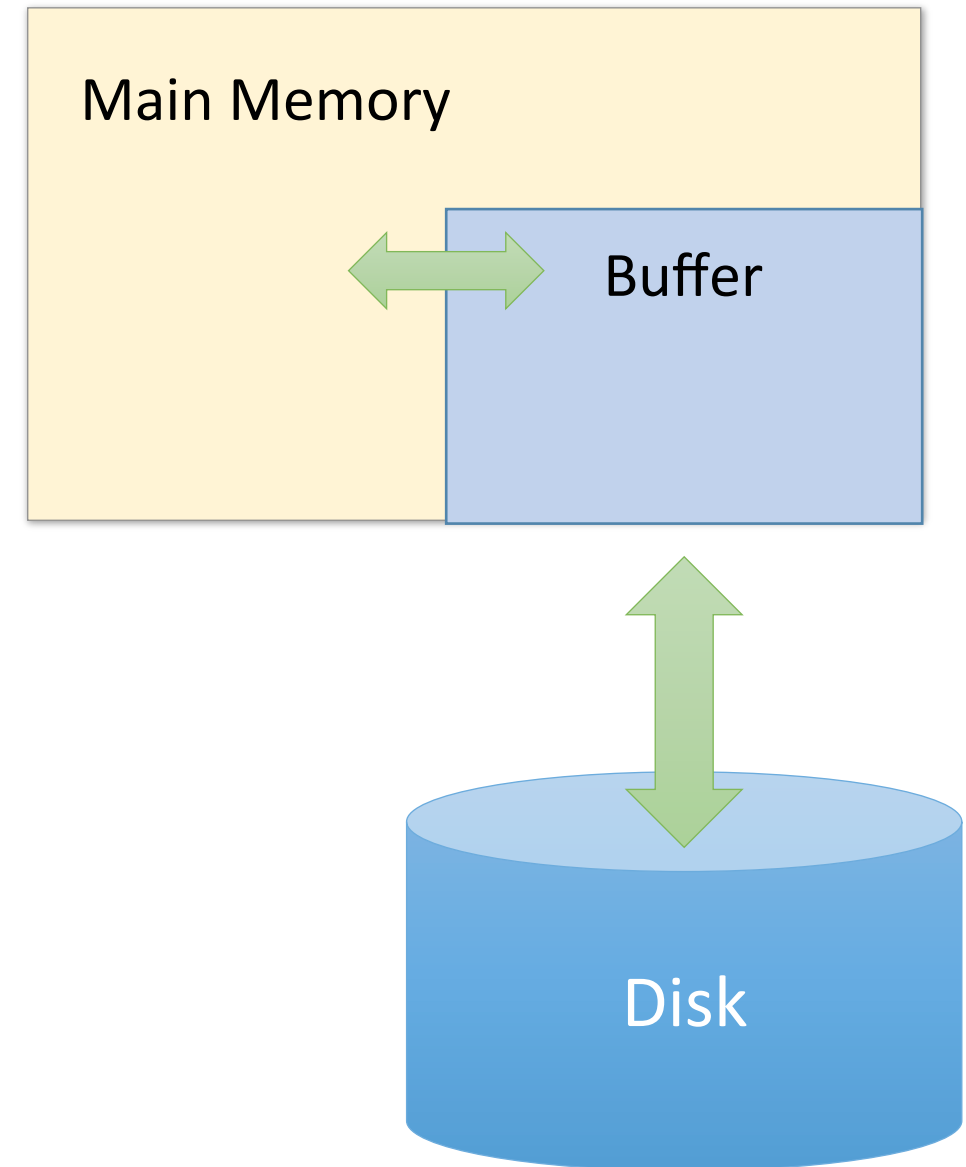
The (Simplified) Buffer

- In this class: We'll consider a buffer located in **main memory** that operates over **pages** and **files**:
 - **Read(page)**: Read page from disk -> buffer *if not already in buffer*
 - **Flush(page)**: Evict page from buffer & write to disk
 - **Release(page)**: Evict page from buffer *without* writing to disk



Managing Disk: The DBMS Buffer

- Database maintains its own buffer
 - Why? The OS already does this...
 - DB knows more about access patterns.
 - Watch for how this shows up! (cf. *Sequential Flooding*)
 - Recovery and logging require ability to **flush** to disk.



The Buffer Manager

- A **buffer manager** handles supporting operations for the buffer:
 - Primarily, handles & executes the “replacement policy”
 - i.e. finds a page in buffer to flush/release if buffer is full and a new page needs to be read in
 - DBMSs typically implement their own buffer management routines

Activity 15!